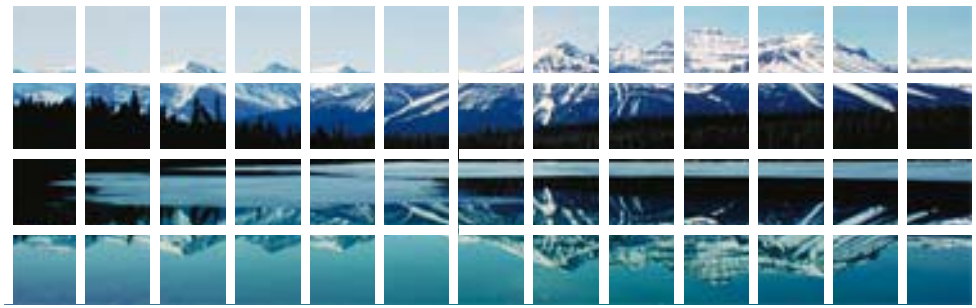
Ballard Power Systems



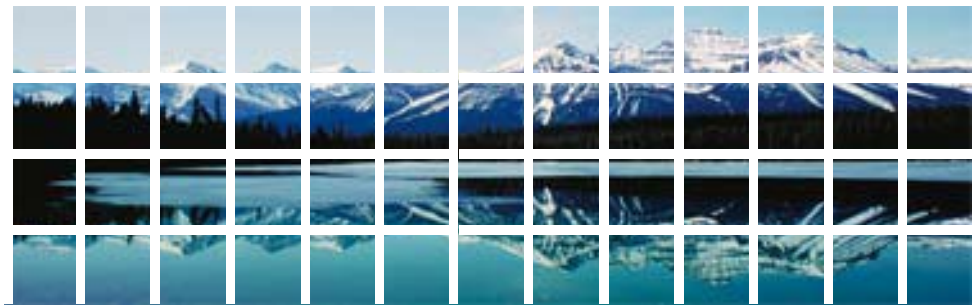
PEMFC Freeze Start

DoE Freeze Start Workshop
February 2005

Ballard Power Systems Inc., R&D

Freeze-start in PEMFCs

- Freeze-Start Issues
- Progress at Ballard
- Avenues for Further progress

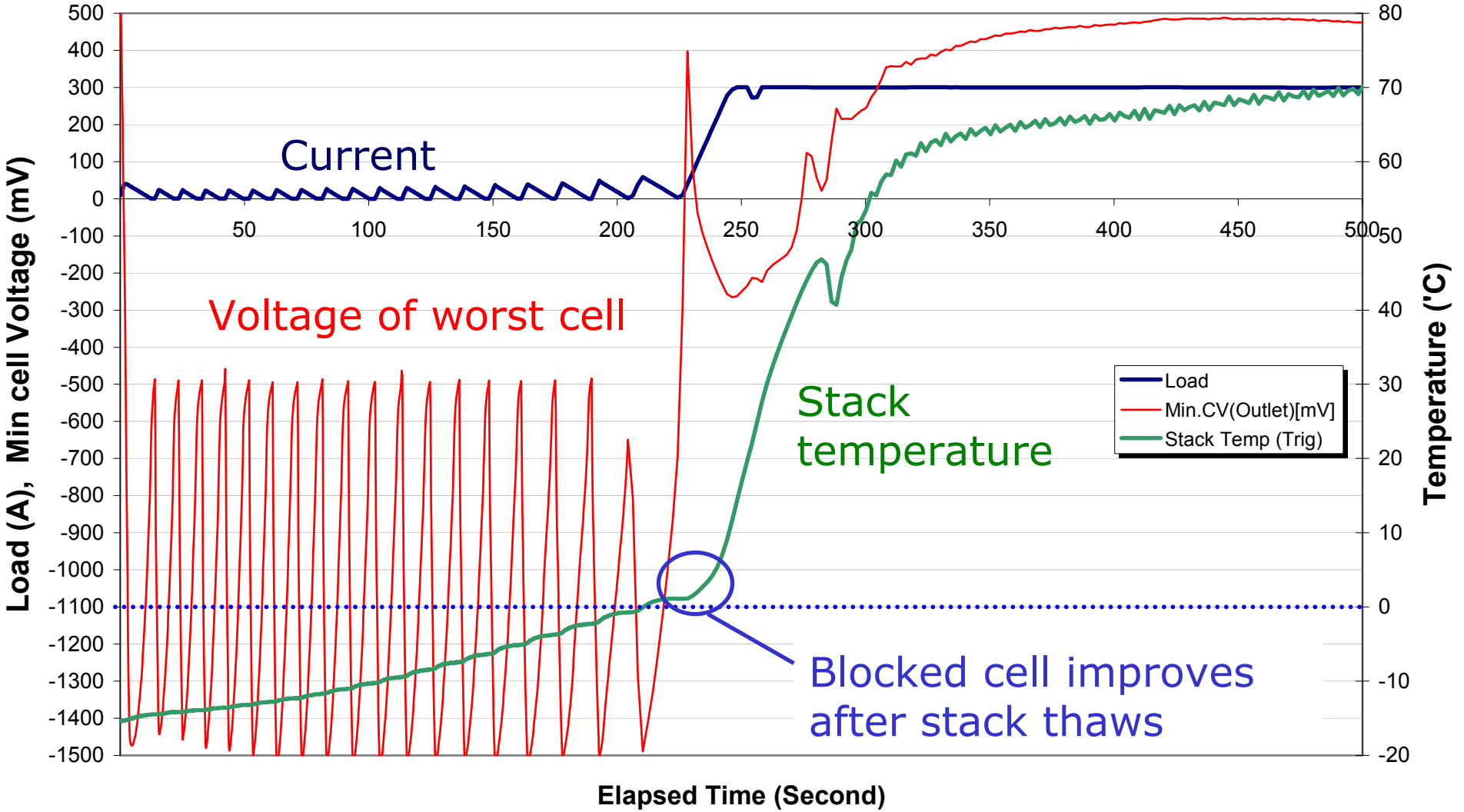


1. Freeze-Start Issues

Some Freeze-start Issues

- Reactions are inherently slower at low temperature (cathode reaction, proton conduction, mass transport); all reducing the cell voltage
- Ice blockage in the unit cell can starve reactants and severely reduce fuel cell performance
- The stack must warm up to a temperature where ice blockages can melt – strongly related to thermal mass
- High fuel efficiency requirements restricts the amount of energy (hydrogen or battery power) that can be spent preparing the system for a freeze-start

Example of slow freeze-start caused by ice blockage



Designing MEAs to tolerate ice blockages (electrocatalyst improvement)

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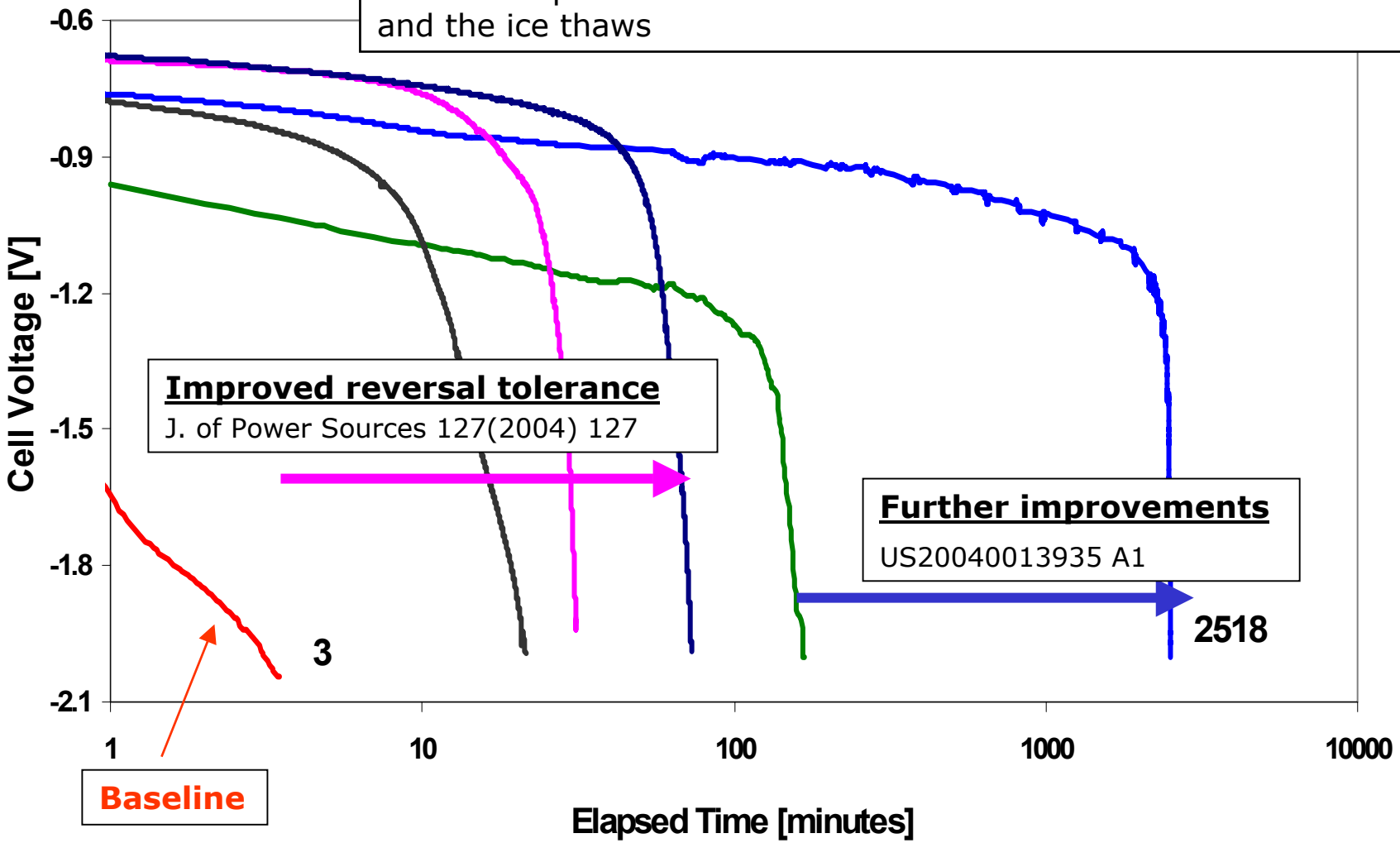
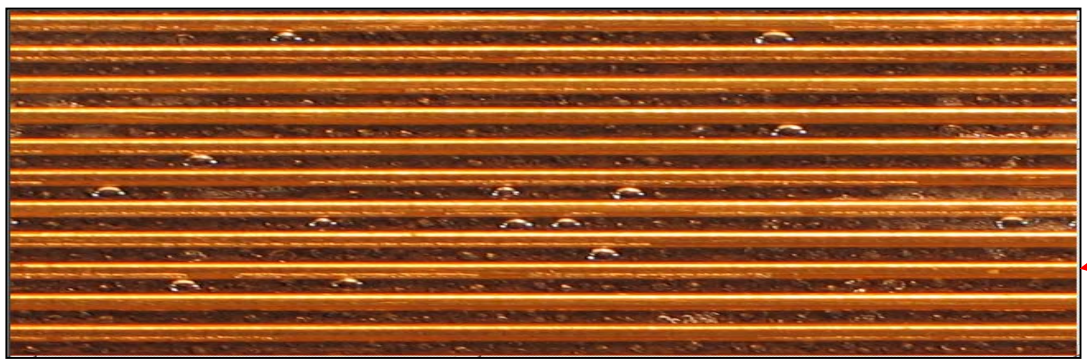
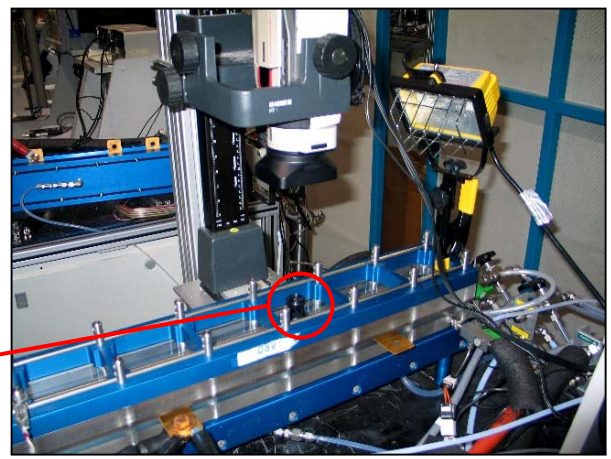
Improved design means that reactant blockages, resulting in this case in deep cell reversal. can be tolerated until the stack warms up and the ice thaws

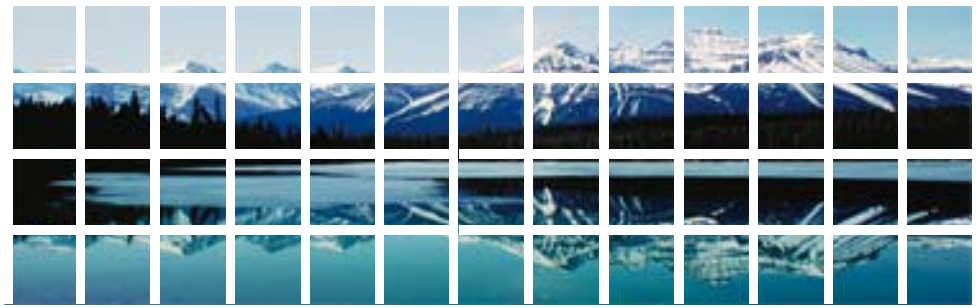


Designing plates to remove water

- Liquid water in the plates can freeze and cause blockages which prevent the reactant from reaching the MEA
- The "flow visualization tool" (clear cell) can be used to optimize liquid water removal, both during regular operation and during shutdown.
- The operation of the cell during subzero start-ups has also been observed





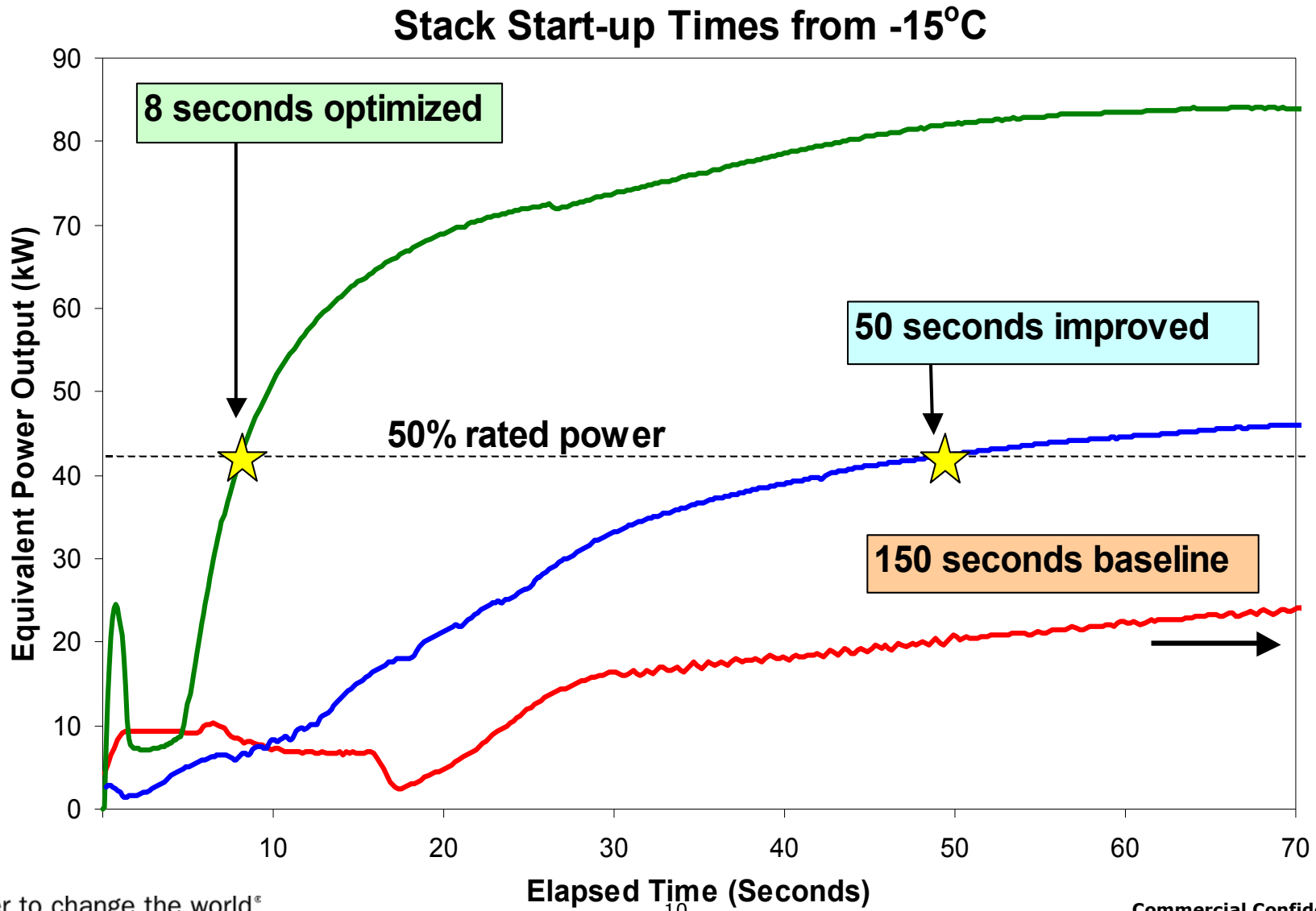


2. Freeze-Start Progress

Freeze-start progress at Ballard

- The following freeze-starts are demonstrated without assistance from the system (i.e. no added heat)
  - 8 second start-up (time to 50% power), from a uniform stack temperature of -15°C
  - Freeze-start from a uniform stack temperature of -30°C also demonstrated
- Freeze-storage down to -40°C, with multiple freeze/thaw cycles and no loss of performance has been demonstrated

Recent improvements in freeze-start efficiency



Freeze-start from -30°C

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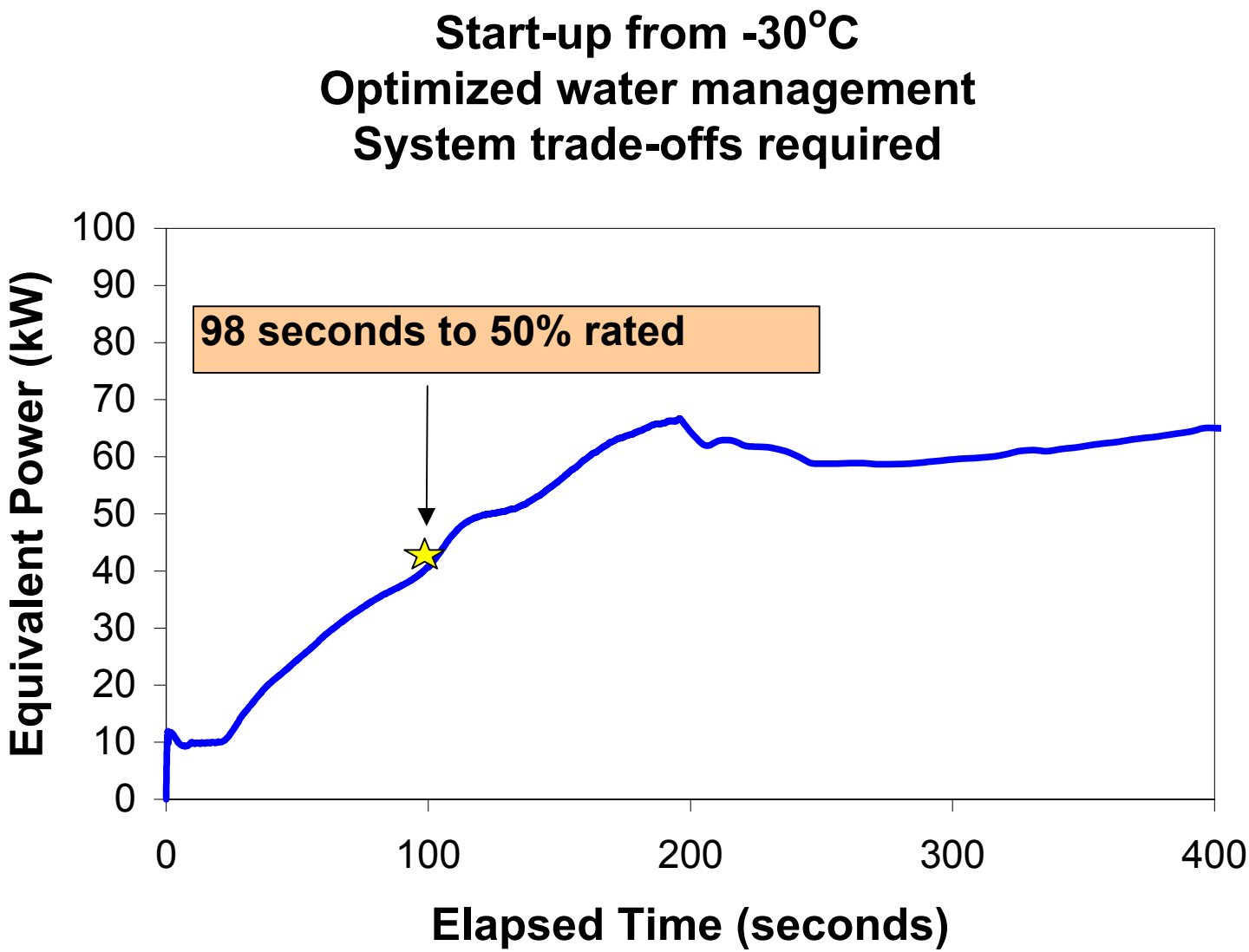

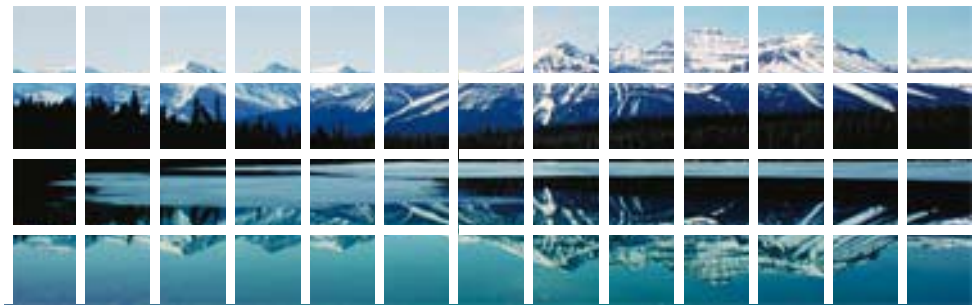

3. Research Paths

Summary

- Over the years freeze-start has been a challenging problem for fuel cell vehicles. Improving freeze-start has required an integrated approach:
  - MEA improvement
  - Plate design
  - Stack hardware design
  - Operation condition optimization
  - Operation protocol optimization
  - System component design
- As a result, significant progress has been made in performing fast, robust start-ups from lower temperature
- Continued fundamental understanding is needed to improve performance at temperatures below -25°C